REDUCING WRINKLING AND TEARING OF DEEP DRAW PART

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ABSTRACT

Some of the most common outcomes in deep drawing process are tearing and wrinkling or the formation of uneven height at the top rim of a drawn part due to the material anisotropy. This project involves experimental and numerical studies of the die design to investigate the formability of sheet metal. The main objective of this project is to obtain the best deep drawing parameters in reducing wrinkle and tearing during a cylindrical cup deep draw process. The project begins with the die design using Computer Aided Design (CAD) software. The project is continued with modelling of finite element model (FEM) using simulation software. The variables for this project are **die clearance, die radius,** and **blank holding force**. The constant of this simulation are thickness of sheet metal and punch size to deform the material. All the data from finite element software showed the different value of displacement. From the data documentation, the discussion and result were concluded to determine the effect of different parameters on wrinkling and tearing phenomenon during sheet metal forming process.

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LIST OF SYMBOLS

A = area to be cut

L = length of material

T = Thickness of material

D = diameter of blank

W = width of rectangle

C = Clearance (per side)

Ø = Diameter

d = Depth of draw

LIST OF ABBREVIATIONS

JIS	Japaneese Industrial Standards
HB	Hardness Brinell
CAD	Computer aided design
mm	millimeters
CNC	Computer Numerical Control
rpm	Revolution per minute
2D	Two dimensional
3D	Three dimensional
FEA	Finite Element Analysis
FEM	Finite Element Model

CHAPTER 1

INTRODUCTION

1.1 PROJECT SYNOPSIS

In sheet metal forming, a blank sheet is subjected to plastic deformation using forming tools to achieve the designed shape. During this process, the blank sheet will develop defects if the process parameters are not selected properly. Failure of sheet metal parts during deep drawing processes usually takes place in the form of wrinkling or tearing. Therefore, it is important to optimize the process parameters to avoid defects in the parts and to minimize production cost. Many variables affect the failure, these includes material properties, the punch and die clearance, the punch and die radius, the blank holding force, the die cavity depth, and the cushion pressure. This experimental project is to overcome the wrinkling and tearing of the deep drawn parts. In this project, an 80 tonnage stamping machine and sheet metals of 1mm thickness are used to produce cylindrical cup shape product with 50mm diameter and 20mm length.

1.2 BACKGROUND OF STUDY

Deep draw stamping is a process that's been widely uses in the manufacturing field especially in the oil and gas industry, the automotive industry, and also used to produces a range of household items such as soup cans, battery casings, fire extinguishers, and even a kitchen sink. A part is called deep drawn if the depth of the part is at least half of its diameter. Otherwise, it is simply called general stamping. A deep drawn part may have one or more drawing operations depending on the complexity of the part. In a deep drawing process, a punch pushes a sheet metal blank into a die cavity, resulting the desired contoured part. Multi stage drawing process of a blank material experiences additional complex deformation in each stage compared to a conventional drawing process. The process generally involves additional bending, stretching, compression and shearing by different drawing ratios during the subsequent drawing stage. The deformation naturally proceeds with the irregular shapes of the cross section and conditions that cause failure such as tearing and wrinkling. Since the deformation mechanism is very complicated and the final mechanical properties are difficult to predict, the process design is not an easy task for the manufacture of a product of desired shape and material properties.

The success or failure of the forming process is influenced by many process parameters such as the drawing ratio in each stage, the difference of the drawing ratio within the cross-section, the shape of the die, the strain-hardening coefficient, material formability, the lubrication conditions and the degree of ironing. One of the key parameters affecting the forming process is the **blank holder force (BHF)**. The advantage of varying the blank holder force during the forming process is the two primary model of failure which are wrinkling and tearing (Fig. 1.1) are avoided. This gives rise to improved formability, higher accuracy and better part consistency.

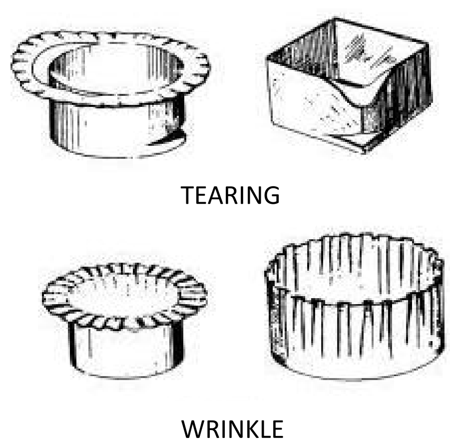

Figure 1.1: Wrinkling & tearing in deep drawing

Source: Huh H. and Kim S. 2001

1.3 PROBLEM STATEMENT

Wrinkling of sheet metal material in deep drawing operations generally occur in the wall or flange of the part. During the process, a blank between a die and a punch is held by means of a blank holding force (BHF). The flange of the blank undergoes radial drawing stress and tangential compressive stress during the stamping process that causes the sheet to buckle locally. The radial tensile stress is due to the blank being pulled into the female die, and the compressive stress, normal in the blank sheet is due to the blank holder force (BHF). The difference in the drawing ratio and the irregular contact condition between the blank and die which occur when using second and third method of redrawing, also induces non uniform metal flow which cause wrinkling, tearing, and severe extension of metal during the redrawing process. On the other hand, fracture or necking occurs in a drawn part which is under excessive tensile stresses. Wrinkling and tearing rupture thus define the deep drawing process limits (Pepelnjak and K. Kuzman, 2007).

Wrinkling and tearing are preventable if the deep drawing system and stamped part are designed properly in term of **die radius, die clearance** and **blank holding force (BHF).** It is important to adjust the blank holder force exerted on the edges of the blank so that it is not just sufficiently great to prevent wrinkle formation at the edges but at the same time not greater than what is necessary as this promotes tearing and furthermore leads to high frictional forces between the blank, the blank holder and the die itself. Such undesired forces cost unnecessarily much energy during deep drawing process which leads to wear and shorten the life of the punch and die.

1.4 OBJECTIVES

1. To design a deep drawing die for cylindrical cup drawing operation.
2. To investigate the effects of draw depth and blank holder force in deep drawing process.
3. To obtain the best deep drawing parameter in reducing wrinkle and tearing during deep draw process.

1.5 SCOPE OF STUDY

Cylindrical cups' drawing is responsible for the manufacture of billions of metal containers. Therefore, in this project a cylindrical cup shaped is studied in term of its **die radius, die clearance, and blank holding force**. A literature review about the process from any previous resource focuses on:

- The design of a cylindrical cup container using CAD software
- The fabrication process and the material used for fabrication
- The formability test using Hyperform software

1.6 PROJECT SPECIFICATION

Size of die	: 280mm x 280mm (L-R x F-B)
Die material	: Mild Steel with 320GPa Young Modulus of Elasticity
Sheet metal material	: Mild steel
Thickness of product	: 1mm
Diameter of cup	: 50mm (outer diameter)
Cup outer radius	: 5mm
Blank size	: Ø105mm
Part draw height	: 20mm
Machine tonnage	: 80 tonne

1.7 PROJECT FLOW CHART

Figure 1.2 shows the overall project flow chart.

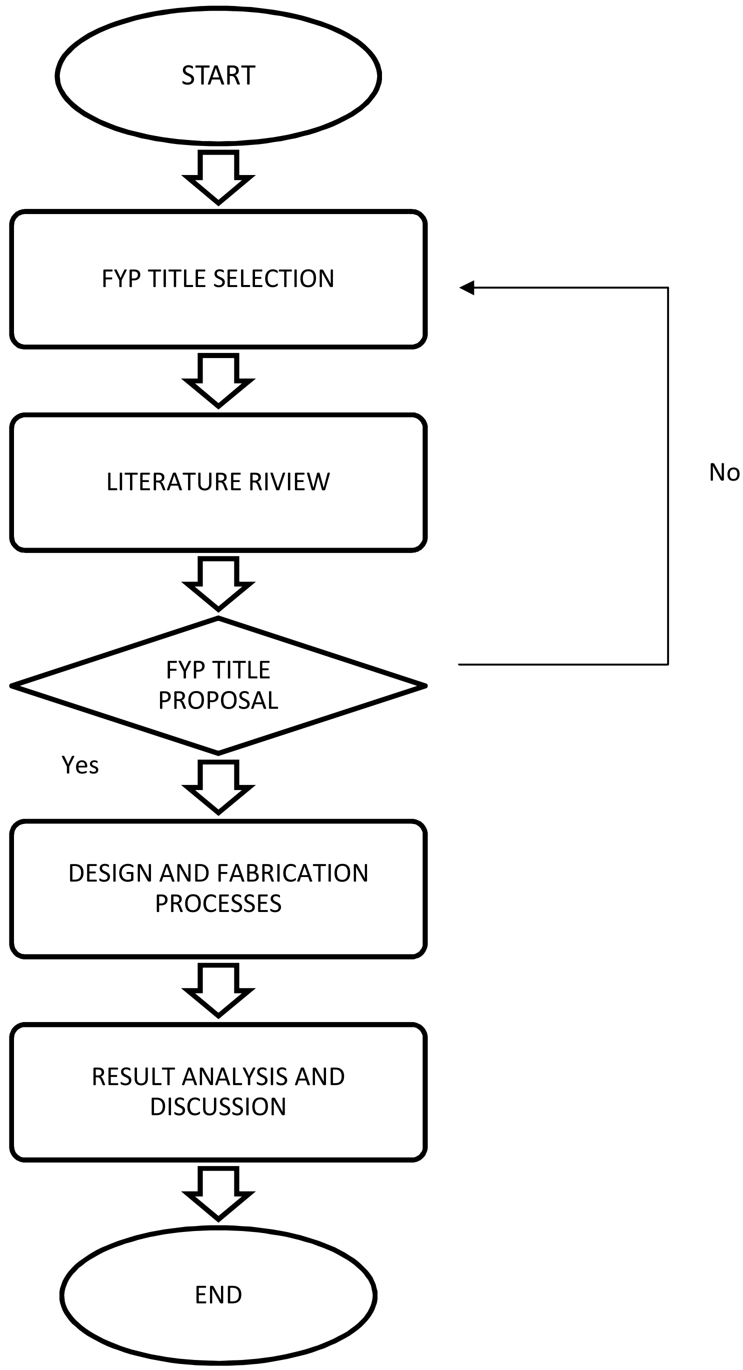

Figure 1.2: Project flow chart

CHAPTER 2

LITERATURE REVIEW

2.1 BASIC CHARACTERISTIC OF SHEET METAL FORMING PROCESS

Sheet metals forming refer to various processes used to convert sheet metal into different shapes for a large variety of finished parts such as aluminium cans and automobile body parts. Deep drawing process is one of the forming processes. The key to the formability of sheet metal is its ductility. Sheet metal parts are usually made in a cold condition but sheet metal parts also are formed in a hot condition as the material will have a lower resistance in hot condition. Blanks are very often used as the initial materials during sheet metal forming. The shape of a part generally corresponds to the shape of the tool (Vukota Boljanovic, 2004). Sheet metal forming process is used for both serial and mass production. Their characteristics are:

- High productivity
- Highly efficient use of material
- Easy servicing of machines
- The ability to employ worker with relatively less basic skills
- Advantageous economic aspects

2.2 MATERIAL SELECTION FOR DIE FABRICATION

Selection of materials for die components is an important activity during die design stage in stamping industries. The knowledge base on the system can be modified depending upon the availability of new materials and advancement in technology. A long life cycle time of all the die components is desired to reduce the maintenance or repairing cost.

2.2.1 Type of Tool Steel

The key components of a deep draw die are the ability of tool steel to withstand the high shock loading involved and to resist the abrasive forces involved. Tool steel refers to a variety of carbon and alloy steels that are particularly well suited to be made into tools. Their suitability comes from their distinctive hardness, resistance to abrasion, their ability to hold a cutting edge, and their resistance to deformation at elevated temperatures. Base from the advantages, tool steel is suitable to be uses in this project. Tool steels are made to a number of grades for different applications. Choice of grade depends on whether a keen cutting edge is necessary, as in stamping dies, or whether the tool has to withstand impact loading and service conditions encountered with such hand tools as axes, pickaxes, and quarrying implements. In general, the edge temperature under expected use is an important determinant of both composition and required heat treatment. The higher carbon grades are typically used for such applications as stamping dies or metal cutting tools (Vukota Boljanovic, 2004). In this project the JIS SKD11 tool steel is chosen as it is a high-carbon-chromium alloy tool steel which is soft annealed to about HB210. It has a good wear resistance and machinability after heat treatment and is suitable for making long life high precision cold work dies.

2.3 MECHANICS OF DEEP DRAWING

2.3.1 Die Concept

Deep drawing die is a metalworking tool that is designed and built to convert raw material into parts that conform to blueprint specifications. Before proceeding with the fabrication, the fundamental of deep drawing process must be known first. In deep drawing, dies are placed into a stamping press and when the stamping press moves up, the die opens. As the stamping press moves down, the die closes. The raw material or blank moves through the die while the die is open, being fed into the die in a precise amount with each stroke of the press. As the die closes, the die performs its work on the metal. The greater the die cavity depth, the more blank material has to be pulled down into the die cavity and the greater the risk of wrinkling in the walls and flange of the part. In stamping, most of the final part is formed by stretching over the punch although some material around the sides may have been drawn inwards from the flange. As there is a limit to the stretching that is possible before tearing, stamped parts are typically shallow. To form deeper parts, much more material must be drawn inwards to form it. One of the most common examples of deep drawing is the cup drawing operation. It is used to produce products such as cartridge bases, zinc dry cells, metal cans and steel pressure vessels (Hosford and Caddell, 2007). It is also used as a method for formability test of sheet metals such as the Swift cupping test (Theis, 1999). Forming a simple cylindrical cup is shown in Figure 2.1.

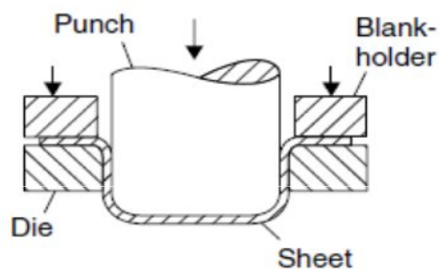

Figure 2.1: Cylindrical cup

2.3.2 Draw Stages

The number of successive draws required is a function of the ratio of the part height, h to the part diameter, d.

$$- = \frac{\quad}{\quad} = 0.5$$

Where :

N = number of draws
h = part height
d = part diameter

The value of N for the cylindrical cup draw is given according to table 2.1.

Table 2.1 Number of draws (n) for a cylindrical cup

h	<0.6	0.6 to 1.4	1.4 to 2.5	2.5 to 4.0	4.0 to 7.0	7.0 to 12
N	1	2	3	4	5	6

Source: Vukota Boljanovic (2004)

Therefore, in this project only one drawing operation is needed to produce the cup according to table 2.1 as the N value is 1.

2.3.3 Die Clearance and Radius

One of the factors that must be considered in determining a die dimensions is the amount of clearance (Fig. 2.2) between the punch and die members. A proper clearance of the die will give the desired force during the stamping process. The radius degree of the punch and die cavity edges control the flow of blank material into the die cavity. Wrinkling in the cup wall can occur if the radius of the punch and die cavity edges are too large. If the radius is too small, the blank is prone to tearing because of the high stresses. Proper clearance application also depends on the material degree of hardness and thickness. (Vukota Boljanovic, 2004).

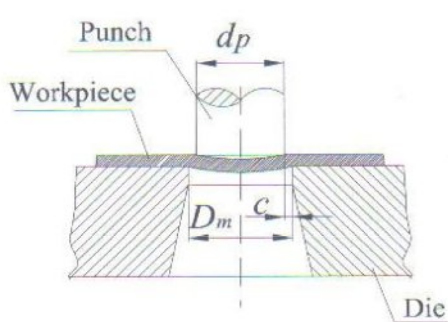

Figure 2.2: Punch & die clearance

Source : Vukota Boljanovic 2004

Table 2.2 illustrates the absolute value for clearance depending on the type and thickness of the material.

Table 2.2: Absolute value for clearance

Material thickness T (mm)	Material			
	Low Carbon Steel, copper and Brass	Medium steel 0.20 % to 0.25% Carbon	Hard steel 0.40% to 0.60% carbon	Aluminum
0.25	0.01	0.015	0.02	0.01
0.50	0.025	0.03	0.035	0.05
1.00	0.05	0.06	0.07	0.10
1.50	0.075	0.09	0.10	0.015
2.00	0.10	0.12	0.14	0.20
2.50	0.13	0.15	0.18	0.25
3.00	0.15	0.18	0.21	0.28
3.50	0.15	0.18	0.21	0.28
4.00	0.20	0.24	0.28	0.40
4.50	0.23	0.27	0.32	0.45
4.80	0.24	0.29	0.34	0.48
5.00	0.25	0.30	0.36	0.50

Source: Vukota Boljanovic (2004)

Punch diameter:

$$C = \frac{Dm - \mathrm{dp}}{2}$$

Where:

C, Clearance per side = 1.1 (thickness 1mm)

Dm = diameter of die

dp = diameter of punch

$$1.1 = \frac{50 \quad -}{2}$$

$$= \mathbf{47.80\ mm}$$

Punch radius:

In this project, a punch with 5mm radius is desired as the final cylindrical cup radius.

2.3.4 Blank Size

The deep drawing process requires a blank. It's a part of metal stamping process (Vukota Boljanovic, 2004). The blank is a piece of sheet metal, typically a disc or rectangle, which is pre cut from the stock material and will be formed into the part (Wang Xi & Cao J, 2000). The volume of the developed blank before drawing should be the same as the volume of the cup after drawing. Provided that the thickness of the material remains unchanged, the area of the workpiece will not change. Thus, the blank diameter may be found from the area of blank before drawing. The cup in Figure 2.3 may be broken into matching components and Figure 2.4 illustrates the area of each component that need to be calculated.

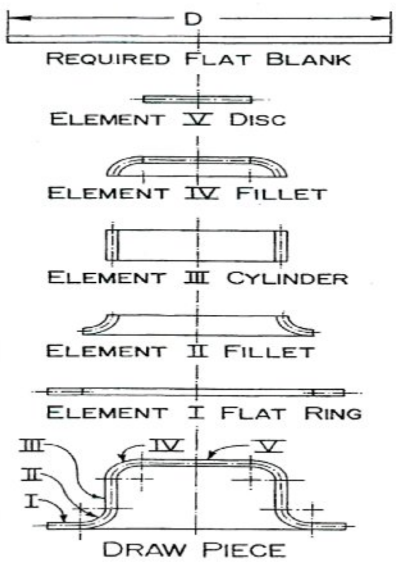

Figure 2.3: Draw element

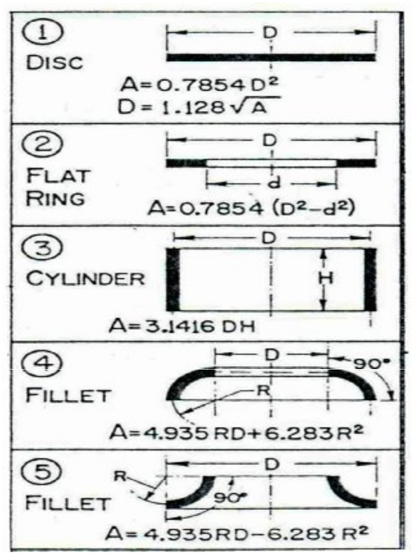

Figure 2.4: Draw area

Figure 2.5 shows the cup size to calculate total surface area.

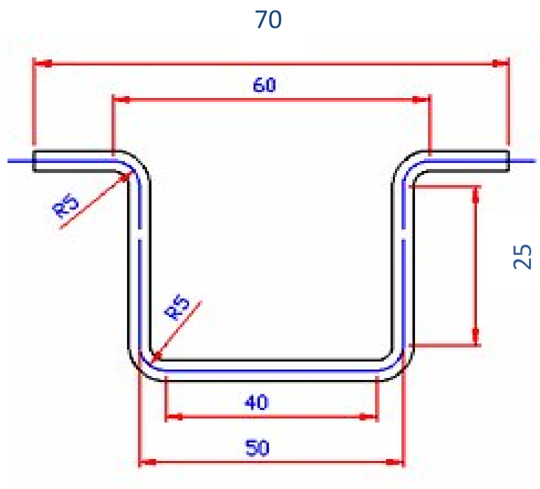

Figure 2.5: Cylindrical cup

Total Surface Area = Sum of Element I to V

Element I (Ring)

Area $= 0.7854 \times (D^2 - d^2)$
$= 0.7854 \times (70^2 - 60^2)$
$= 1021.02\ mm^2$

Element II (Inner Fillet)

Area $= (4.935 \times R \times D) - (6.283 \times R^2)$
$= (4.935 \times 5 \times 60) - (6.283 \times 5^2)$
$= 1323.4\ mm^2$

Element III (Cylinder)

Area $= 3.1416 \times D \times H$
$= 3.1416 \times 50 \times 25$
$= 3927$ mm2

Element IV (Outer Fillet)

Area $= (4.935 \times R \times D) + (6.283 \times R^2)$
$= (4.935 \times 5 \times 40) + (6.283 \times 5^2)$
$= 1144.1\ mm^2$

Element V (Disc)

Area $= 0.7854 \times D^2$
$= 0.7854 \times 40^2$
$= 1256.7\ mm^2$

Total surface area = Sum of Element I to V
$= 8672.22 mm^2$

Area of flat blank $= 0.7854 \times D^2$

Diameter of flat blank $= \sqrt{\text{Area} / 0.7854}$
$= \sqrt{8672.22 / 0.7854}$
= 105.08mm
= 105mm

2.3.5 Limit Draw Ratio

In deep drawing, the limits for the permissible deformation are set by the draw ratio. The draw ratio is used to:

i. Determine how many drawing operations are necessary to produce a drawn part;
ii. Judge the drawability of deep drawing steels;
iii. Determine the correction value $n = f$ (draw ratio) to calculate the drawing force.

The critical forming parameter for cylindrical cup drawing is the limit drawing ratio (LDR), which is the ratio of the maximum blank diameter to punch diameter that can be drawn in one draw operation.

$$\text{LDR} = \frac{\text{maximum blank diameter, D}}{\text{punch diameter, d}} = \frac{105}{47.8} = 2.2$$

Table 2.3: Mean values for $\beta_{permissable}$

Mean values for $\beta_{0\ perm}$, e.g. for WUSt 1403, USt 1303, Ms 63, Al 99.5

d/s	30	50	100	150	200	250	300	350	400	450	500	600
$\beta_{0\ perm}$	2.1	2.05	2.0	1.95	1.9	1.85	1.8	1.75	1.7	1.65	1.60	1.5

Source: Heinz Tschaetsch (2006)